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Performance Testing of a Passive Low-Velocity Filtration Strainer for Use in Excluding Zebra Mussel Post Larvae from Water Intake Systems

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PURPOSE: This technical note describes the evaluation of a low-velocity filter system to effectively reduce or eliminate zebra mussel post larvae from entering a water intake system. Zebra mussel larvae enter water intake systems where they can attach to and grow on pipes and equipment. Over time, they can cause significant operational and/or maintenance problems within the pipes and equipment to which they attach. The removal of these mussels and the downtime caused to the operation can be costly.

BACKGROUND: Beak Consultants, Inc., Lancaster, NY, in consultation with Performance Contracting, Inc. (PCI), selected southern and northern sites to conduct these filter efficiency studies. The objective was to evaluate PCI's passive filter system for potential control of the macrofouling zebra mussel (*Dreissena polymorpha*), which invaded North America from Europe in the mid-1980's. It was assumed that the related quagga mussel (*Dreissena bugensis*) would be similarly controlled by filtration. Furthermore, filtration might also reduce densities of the Asiatic clam (*Corbicula fluminea*). None of the three bivalves is indigenous to North America and all are aquatic nuisance species.

Preliminary work involved technical review and consultation with malacologists and field studies to estimate filter mesh opening sizes that could exclude the late planktonic and older life stages of zebra mussels. For effective control of *D. polymorpha*, a filter mesh must exclude adults, juveniles, and most, if not all, settlement stage mussels. However, to be practical the mesh must also be large enough to pass most organic and inorganic suspended solids for long periods of time.

The mesh size selection criteria were based on the following:

- Zebra mussel size at metamorphosis from the planktonic larval to benthic settlement stage, using expert opinion and data from unrelated field studies.
- Engineering estimates of the particle size of suspended solids in the water.
- A preliminary field test of filter mesh.

In the preliminary efforts it was determined the majority of settling zebra mussels would be greater than 300 μm (0.30 mm) in length. It was also determined that if smaller mussels were to settle, the physiological stress of metamorphosis and settlement combined with small size would result in their death in the short term. Available limnological data used by engineers indicated that suspended particles would typically be much smaller than the cross-sectional dimensions of settling mussels. Preliminary field tests using fiber mesh media (with openings ranging from 150 to 200 μm) indicated the suspended solids at the Louisiana site clogged this medium relatively rapidly. With this

information in hand, PCI selected an off-the-shelf, single-layer, stainless steel woven wire filter medium with a mesh opening size of 234 μm (± 5 percent).

The tests were designed to determine for a given filter criterion and flow rate the effectiveness of filter(s) in reducing zebra mussel post larvae settlements downstream of the intake. The pump head loss, increasing over time, was also recorded to establish the frequency by which filter cleaning or replacement would be required.

The tests were conducted between May and December 2001 on raw water intakes in the southern and northern United States: the lower Mississippi River at LaPlace, LA, and a later test at Lake Ontario at Rochester, NY.

DESIGN: The low-velocity filter system evaluated was a PCI SureFlow™ Strainer designed to control the approach velocity of water uniformly through pleated filters using a patented internal flow control device (Figure 1).

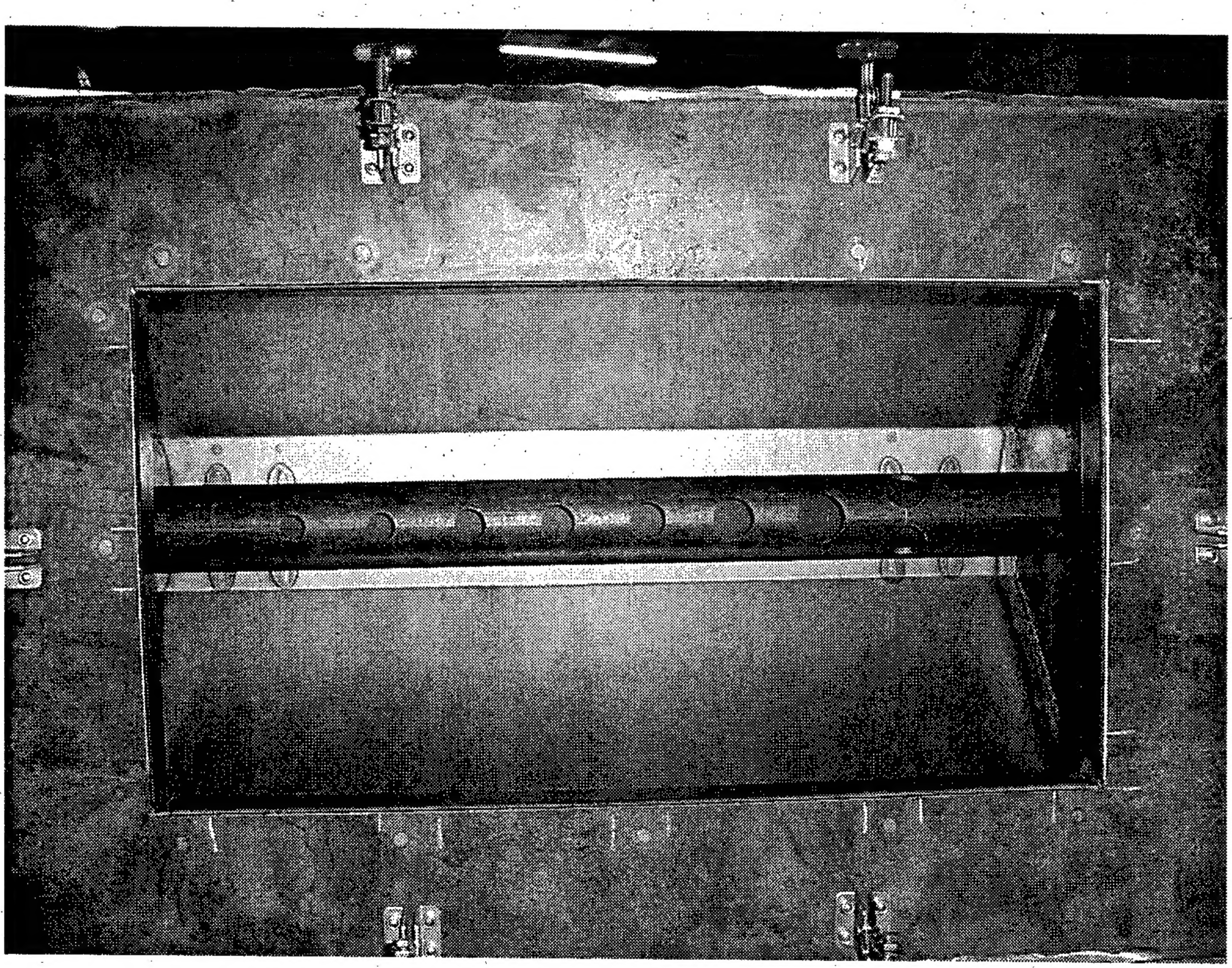

Figure 1. PCI's patented flow control device inside the filter boxes draws water uniformly across the face of the pleated filter(s)

Sections of pleated, reinforced wire mesh media were sealed with epoxy into rectangular stainless steel filter modules. In the field, modules were fit into custom-built receptacles (Figures 2 and 3). The module-receptacle system was inside a main or common tank. Water was withdrawn from the main tank either through the filter systems that lead to the treatment tanks or the unfiltered system to the control tanks (Figures 4 and 5). Flow to the treatment tanks initially was set slightly higher than flow to control tanks in anticipation of some flow reduction due to filtration.

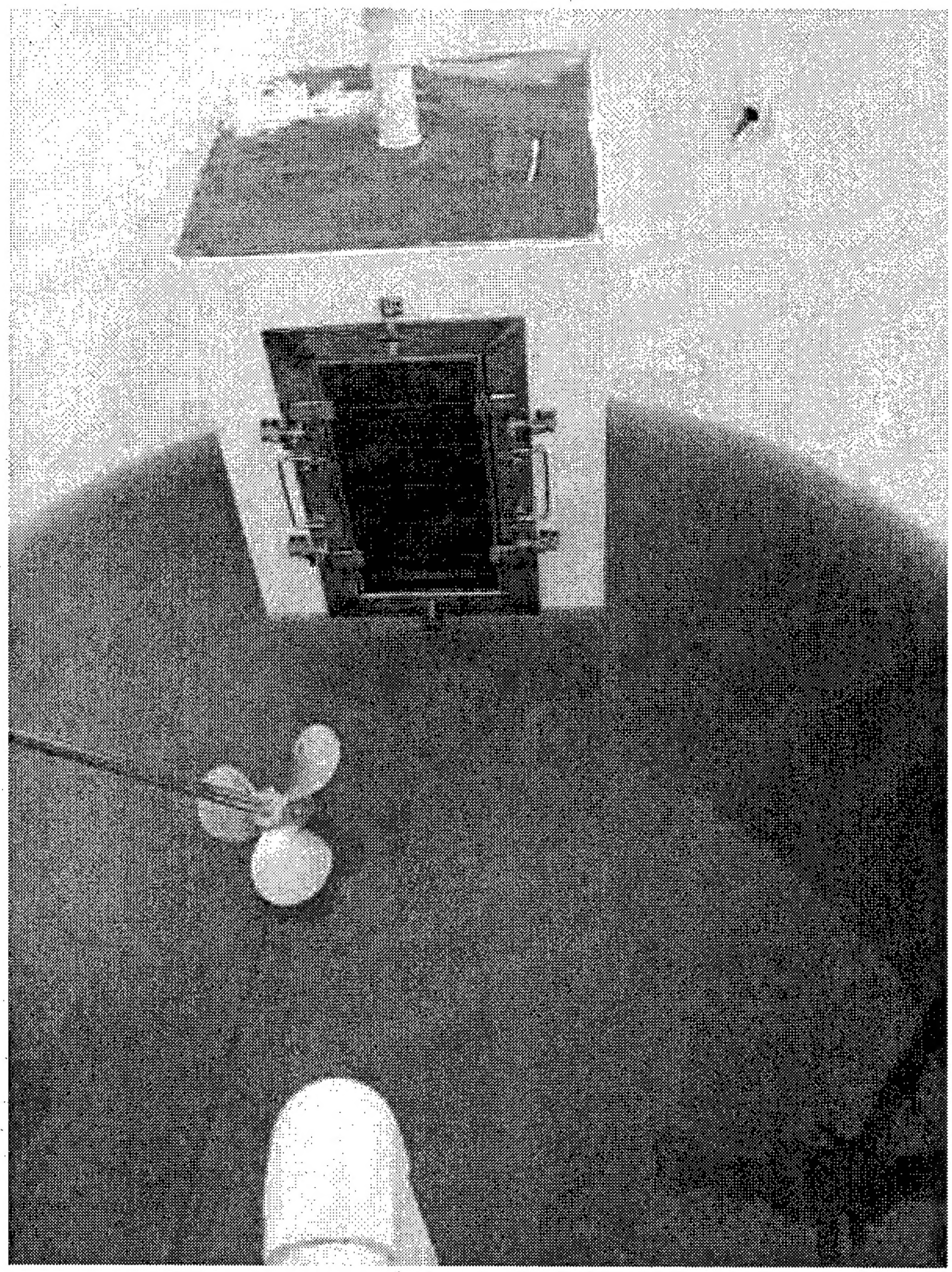

Figure 2. Filter box set inside Tank 1 for field trials at the Mississippi River site. Filter face was 8 by 16 in. (0.2 by 0.4 m) with 3.5-in.- (0.09-m-) deep pleats. A pleated pre-screen was also used, sized 8 by 16 by 1 in. (0.2 by 0.4 by 0.03 m) deep in this photograph. Deep pleated pre-screens (2 in. (0.05 m)) were also used in the trials later. A paddle mixer was used to prevent settling of solids and sediments

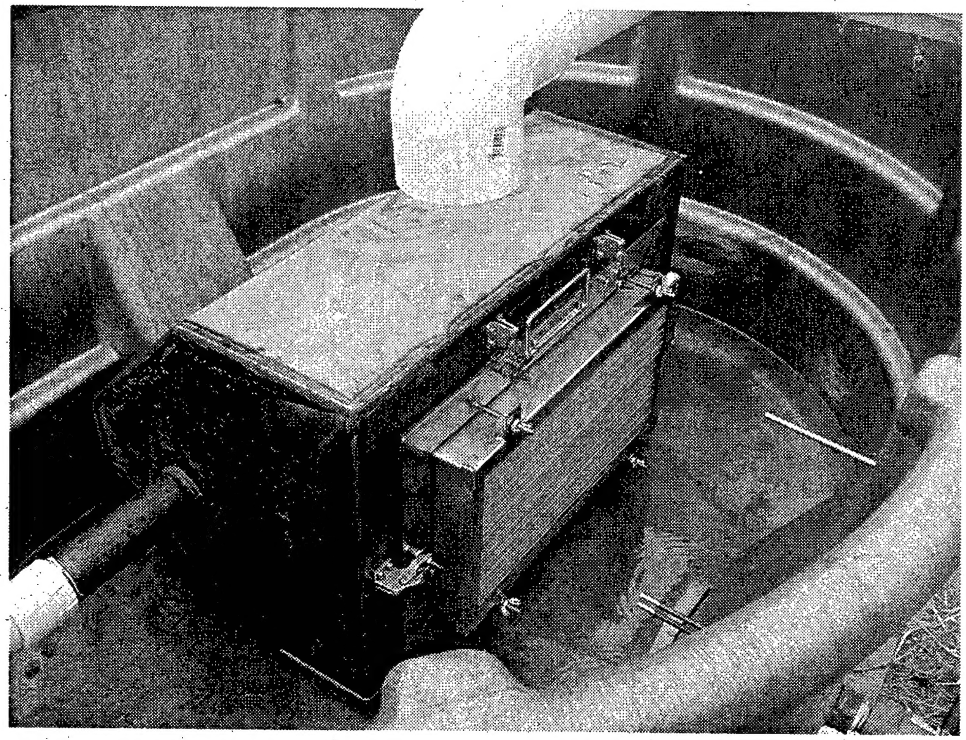

Figure 3. Filter box set inside tank for trials on Lake Ontario site. The filter face was 8 by 16 in. (0.2 by 0.4 m) with 3.5-in.- (0.09-m-) deep pleats. A pleated pre-screen measuring 8 by 16 by 2 in. (0.2 by 0.4 by 0.05 m) deep was also used

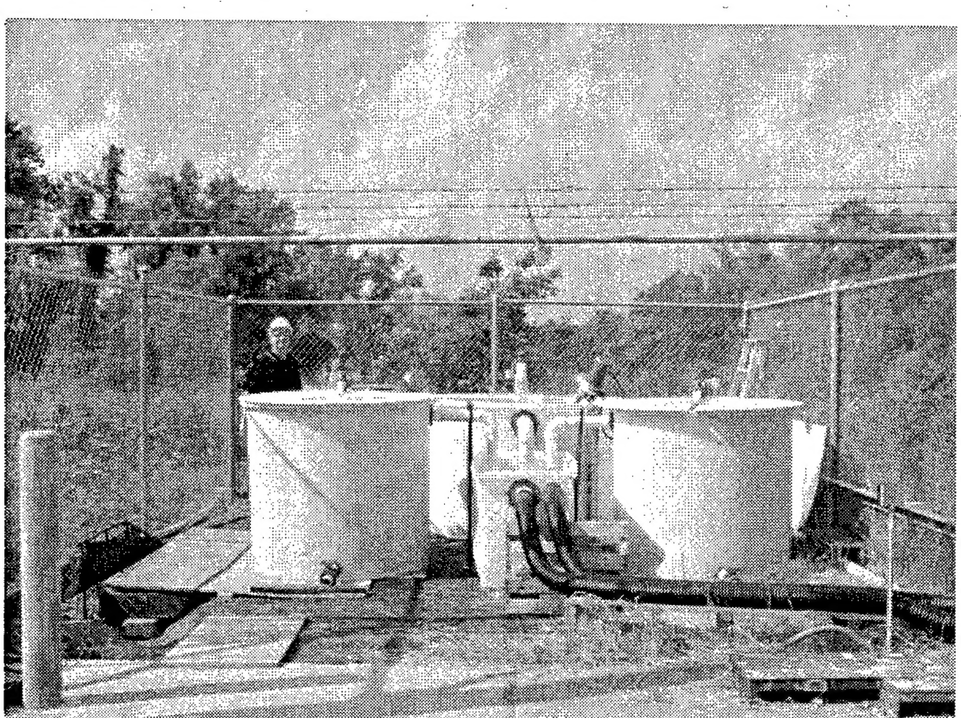

Figure 4. Trial set up on the Mississippi River near LaPlace, LA. Tank 1 is the collection tank in the back center and contains the filter box. Tank 2, on the left, receives the filtered water. Tank 3, on the right, is the control tank receiving unfiltered water from the Mississippi River

Figure 5. Trial set up on Lake Ontario, Rochester, NY. Tank 1 is the water collection tank on the platform, and contains the filter box. Tank 2, the right front tank, receives the filtered water. Tank 3, in the back, is the control tank receiving unfiltered lake water

At the Mississippi River site (Entergy's Little Gypsy Power Plant), three polyvinyl chloride (PVC) plates were placed in a tank receiving filtered water (i.e., the experimental treatment). Six PVC plates were placed in the treatment tank at the Lake Ontario site (Rochester Gas and Electric Russell Station). Depending on the site, three or six plates were also placed in the tank receiving a flow of unfiltered (untreated) river or lake water (the experimental control). T-type diffusers were installed on the inlets to the treatment and control tanks; holes of graded size were drilled into the arms of the T's to better distribute flow across a diffuser and around test plates. The plates were equally spaced and suspended in front of the diffusers located near the centers of each tank.

The PVC plates were immersed for 15 to 105 days prior to retrieval (time varied depending on logistics, environmental, or system conditions). When the plates were retrieved, the surface of each plate was carefully scraped to remove any periphyton or other material adhering to the plate. Typically the material scraped from each plate was placed in a separate, prelabeled sample bottle. The samples were analyzed in a laboratory using dissecting microscopes to determine the number of settled mussels on a plate. During the counting process several mussels from each plate were subsampled and measured, the mussel selection based on general size category (largest and smallest). The fouling density of mussels (number/m^2) for each plate and/or for all plates combined

was determined. Treatment and control tank walls were also scraped to provide secondary settlement data. The condition of filter media, gaskets, seals, and distribution of silt or other solids within the pleats were evaluated; characteristics of sediments in treatment and control tanks were noted.

Although the zebra mussel was the first aquatic nuisance species to invade Lake Ontario, and dominated at that study site until the late 1990s, settled quagga mussels were dominant when the study was conducted. Given the dominance of the quagga mussel, it was expected and is probable that settlement at the lake site was heavily weighted toward this species. At the Louisiana site only zebra mussels were expected. It was not practical to differentiate between dreissenid species, and so the mussels were not positively identified as *D. polymorpha* or *D. bugensis* at either site. The Asiatic clam is common in the lower Mississippi River and is easily identified. Early umbonal forms of the Asiatic clam are sometimes found in the plankton although this species does not have a truly planktonic veliger stage as do dreissenids.

Supporting information on presence of planktonic mussels and potential for later fouling was provided by sampling with a plankton net (64 µm, 0.5 m). Plankton samples were immediately examined using dissecting microscopes and cross-polarized lighting techniques (the latter allow *Corbicula* and *Dreissena* to be readily distinguished). The density (number/m^3) of planktonic veligers as well as transitional D-form and umbonal-form post veligers was determined.

RESULTS AND DISCUSSION: Silt and other particulates typically partially clogged meshes, the material residing primarily in the recesses of the pleats. Clogging resulted in high-pressure differentials that often distorted filters, and in some cases breaches were visible in the media and/or gaskets. At the Lake Ontario site, limited microscopic examination indicated about 90 percent of the clogging particulates were 20 µm or less despite a 234-µm filter mesh.

A media breach was not always obvious; small breaches possibly went undetected. When a breach was documented, the specific time it occurred was unknown, as was the proportion of water passing unfiltered through a breach versus intact sections of the media. These factors obviously confounded interesting biological results.

Mussel settlement occurred on either all or none of the replicate plates at each site, suggesting reasonable mixing or distribution of the water, at least in the area around the plates. However, variability in mussel density among plates in treatment or control tanks was apparent and ranged from a factor of about three to ten. The variability was probably related to plate position and flow differences through individual discharge ports in the inlet diffusers.

Water clarity was typically much higher at the Great Lake site than at the Mississippi River. However, clogging was also noted at the lake site, and could have been due to bottom silt re-suspended during storms or to plankton blooms. Qualitative observation indicated that less silt was adhering to the plates and walls in the treatment than in the control at the Lake Ontario site.

Mussel settlement data are discussed first for the Mississippi River trial and then the Lake Ontario trial. Both data sets are summarized in Table 1.

Little or no effect of control versus treatment filter type on dreissenid settlement was observed in the Mississippi River experiment. Settlement densities of mussels on control plates in the river study

ranged from 0 to 120 individuals per m^2. For the 11/01/01 collection, mean density was 74.7 individuals per m^2, which was low compared to previous, unrelated monitoring data from nearby sites. It is likely that this settlement occurred from late September through October, which is consistent with peaks in settlement observed in studies at nearby sites. Some settlement was expected in November, but none was observed (density was 0 in the 12/17 data collection). Qualitative inspection of tank sediments for adult Asiatic clams indicated the clam was considerably more abundant in the control than treatment tank.

Settled zebra mussels at the Mississippi River site on 1 November were all greater than 600 μm (0.6 mm) in length, with a maximum of 7.5 mm. Logistics and budgets resulted in the plates being in place from about mid-July to 1 November. The size of the larger mussels found on the plates was unexpected. Settlement associated with fall spawning typically begins as water temperatures fall from stressfully high summer levels, typically no earlier than mid-September. Therefore, mussels found on plates on 1 November probably had only 45 days or less to grow (rather than the full 105 days elapsed time). Also, reasonable expectations are that zebra mussels metamorphose and settle at lengths of approximately 300 to 500 μm and then grow at a rate not likely to greatly exceed 20 μm per day. Thus, the greatest expected length was less than 2 mm. Those mussels found that were much larger than expected possibly settled in the spring elsewhere (e.g., cool deep water) and later were translocated to the test tanks.

Mussels in treatment tanks were slightly smaller than those in control tanks. Possibly this is an artifact of small samples with high variance. Another possibility is that mesh or "filter cake" (silt buildup) selectively excluded larger settlers.

The filter demonstrated no effective control of dreissenid mussels at the Lake Ontario site. In fact, on two dates more mussels were found on plates in filtered than unfiltered water. If the mesh had no effect or was breached, inherent sample variance (estimated to be <10 percent) might account for this unexpected result. However, the magnitude of the differences was sufficient to suggest that other factors may have affected results. It is possible that differences reflect combined effects of higher treatment tank flow rate, variation in position of filter and control inlets, and filter breaches. Also, the unusually small size of the planktonic mussels (as suggested by the minimum sizes of settled mussels on 1 October) was a potential factor.

Mean mussel densities at the Lake Ontario site ranged from 529 to 8,172/m^2. Facility personnel considered the latter settlement density relatively high compared to settlement densities in recent years.

The fact that settlement density was high in the October-November period differs from mid-1990s observations of major settlement during a very short period (2 to 3 weeks) in September, with negligible subsequent settlement. However, fall was mild in 2001; atypically warm lake temperatures appear to have resulted in an extension of the spawning and settlement period. Regardless, settlement clearly continued into October and probably November (the smallest mussel found in the 30 November sample was only 310 μm).

The overall mussel sizes were larger in the October-November plate samples compared with those of the mussels settled in September. Whether this difference was due to immersion duration differences (15 and 22 days for 9 September and 1 October samples versus 60 days for 1 November samples) or

differences related to the ratio of settling zebra versus quagga mussels, is unknown. Quagga mussels composed the majority of the adult mussel population in the vicinity of the Lake Ontario site, and settlers were probably predominantly this species.

Settlement peaked in September in concordance with mid-1990s observations when the zebra mussel was still the dominant species at the site. However, the size of smallest mussels settled in 2001 (~200 µm or 0.2 mm) was smaller than expected or observed in the limited amount of size data collected previously at this site and smaller than the generally expected settlement size of *D. polymorpha*. This suggests that quagga mussels (*D. bugensis*) might settle at a smaller size than zebra mussels. It is also noteworthy that at least one lake seiche with a short-term, high temperature drop recovery was noted in plant records for September. This or other lake seiches might have triggered rapid metamorphosis and settlement of small mussels (zebra or quagga), which otherwise would have settled later in the fall after a longer planktonic growth period. Another possibility is that plates used to monitor zebra mussel settlement rate (and size) by these researchers and other investigators have typically remained in the water for 30 or more days. The additional 8 to 15 days of growth time over the present study may indicate a slight underestimation of the size of settling dreissenid mussels in previous studies.

Regardless, the size of the smallest mussels measured on 9 September and 1 October (200-240 µm) suggests that many could have passed through a 234-µm mesh.

Intermittent plankton net samples (Table 2) collected at the Mississippi River site indicated planktonic mussels were present each time samples were collected. The maximum density of the D-form and umbonal form mussels was ~140,000/m^3 in mid-June 2001. For comparison, densities at a nearby downriver site were >220,000/m^3 in June of 2000. Samples collected at the Lake Ontario site were not analyzed.

At the Louisiana site the secondary settlement data obtained by scraping the treatment and control tank walls (Table 3) indicated settlement on walls (0-25/m^2) was typically lower than on the plates, which were maintained in the central area of the relatively large tanks. Lower water velocity and circulation along walls compared with flow around plates probably influenced settlement on the walls. The tanks were relatively smaller at the Great Lakes site and densities on the walls there were high, ranging from approximately 6,000 to 25,000 mussels per m^2.

SUMMARY: Sediments fouling the pleated 234-µm filter media caused the filters to clog much more rapidly than calculated. Silt fouling rate exceeded the engineering design criteria. Clogging and filter breaches confounded analysis regarding control of settlement-stage dreissenid mussels. Even where breaches were not suspected, the media provided little or no control efficacy. Although the concept for using small mesh filters for control of immature zebra mussels had merit, in practice these filters fouled far too quickly to be practical.

Limited data suggested a 234-µm mesh might reduce passage of Asiatic clam larvae, although clogging remains problematic. The length of settled dreissenid mussels (often ~200 µm) at the Lake Ontario site were much smaller than observed in previous, unrelated studies, perhaps reflecting a high relative abundance of quagga mussels, short durations for immersion of settlement plates, or premature settlement of either quagga or zebra mussels associated with lake seiches.

POINTS OF CONTACT: For additional information, contact Dr. Barry S. Payne (601) 634-3837, *Barry.S.Payne@erdc.usace.army.mil*, or the Manager of the Aquatic Nuisance Species Research Program, Mr. Glenn G. Rhett (601) 634-3717, *Glenn.G.Rhett@erdc.usace.army.mil*. This technical note should be cited as follows:

> Payne, B. S. (2003). "Performance testing of a passive low-velocity filtration strainer for use in excluding zebra mussel post larvae from water intake systems," *ANSRP Technical Notes Collection* (ERDC/TN ANSRP-03-3), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/ansrp*.

Table 1
Mussel Settlement on Plates

Sample Date	Treatment		Filtered Water (Treatment)					Control			Treatment			Control		
	# Settled	Plant	Plate	# Umbonal/ Settled	# Normal Settled	Number of Days	Number Settled /m^2	Plate	Number of Days	Number Settled /m^2	Smallest Mussel Measured in mm	Largest Mussel Measured in mm	N	Smallest Mussel Measured in mm	Largest Mussel Measured in mm	N
07/19/2001	940	Little Gypsy	T-1			79	23	C-1	79	7						
07/19/2001	600	Little Gypsy	T-2			79	7	C-2	79	10						
07/19/2001	3040	Little Gypsy	T-3			79	16	C-3	79	26						
Mean for 7/19/2001 >>							**15.3**			**14.3**						
11/01/2001		Little Gypsy	TT-1			105	26	CT-1	105	110	0.77	3.70	8	0.69	5.00	8
11/01/2001		Little Gypsy	TT-2			105	78	CT-2	105	168	0.59	4.50	20	0.78	4.40	20
11/01/2001		Little Gypsy	TT-4			105	120	CT-4	105	74	0.67	4.00	20	0.73	7.50	20
Means for 11/1/2001 >>							**74.7**			**117.3**	**0.677**	**4.067**		**0.733**	**5.633**	
12/17/2001		Little Gypsy	TRP			46	0	CRP	46	0						
12/17/2001		Little Gypsy	TMP			46	0	CMP	46	0						
12/17/2001		Little Gypsy	TLP			46	0	CLP	46	0						
Means for 12/17/2001 >>							**0**			**0**						
09/09/2001		Russel	All			15	903	SC-1	15	1274	0.22	0.87	8	0.24	0.70	10
Plates scraped & pooled 9/9/2001 >>							**903**			**1274**	**0.22**	**0.87**		**0.24**	**0.70**	
10/01/2001		Russel	T-1			22	5546	C-1	22	14632	0.21	0.39	10	0.20	0.32	10
10/01/2001		Russel	T-2			22	3540	C-2	22	11564	0.24	0.42	10	0.22	0.36	10
10/01/2001		Russel	T-3			22	17936	C-3	22	7021	0.20	0.35	10	0.22	0.35	10
10/01/2001		Russel	T-4			22	14868	C-4	22	9912	0.24	0.81	10	0.20	0.67	10
10/01/2001		Russel	T-5			22	9440	C-5	22	1652	0.21	0.39	10	0.21	0.36	10
10/01/2001		Russel	T-6			22	8024	C-6	22	4248	0.21	0.78	10	0.24	0.45	10
Means for 10/1/2001 >>							**9892.3**			**8171.5**	**0.217**	**0.525**		**0.215**	**0.420**	
11/30/2001		Russel	T-1			60	690	C-1	60	254	0.50	4.50	20	0.45	1.90	20
11/30/2001		Russel	T-2			60	625	C-2	60	124	0.31	2.80	20	0.50	1.50	20
11/30/2001		Russel	T-3			60	3705	C-3	60	389	0.50	2.70	20	1.10	9.40	20
11/30/2001		Russel	T-4			60	1156	C-4	60	667	0.70	4.10	20	0.43	2.50	20
11/30/2001		Russel	T-5			60	761	C-5	60	1481	0.60	1.60	20	0.43	1.10	20
11/30/2001		Russel	T-6			60	690	C-6	60	260	0.43	2.10	20	0.33	2.10	20
Means for 11/30/2001 >>							**1271.2**			**529.2**	**0.507**	**2.967**		**0.540**	**3.083**	

Table 2
Plankton (D-form Veliger and Umbonal) Densities, Little Gypsy Plant

Sample Date	Treatment	Filtered Water (Treatment)						Control Water					
	# Settled	Number of D-form /m³	Number of Umbonal Form/m³	Total Plankton /m³	Smallest Measured in mm	Largest Measured in mm	N	Number of D-form /m³	Number of Umbonal Form/m³	Total Plankton /m³	Smallest in mm	Largest in mm	N
05/01/2001	153	5990	84	**6074**	0.08	1.43	82	6534	69	**6603**	0.08	1.63	26
06/12/2001	940			**27037**	0.11	0.14	6			**30476**	0.13	0.25	21
06/13/2001	600			**22936**	0.14	0.21	9			**25026**	0.11	0.28	8
06/13/2001	3040			**164021**	0.17	0.24	9			**99735**	0.20	0.29	8
06/13/2001	2520					0.17	1					0.27	1
06/14/2001				**104603**	0.13	0.20	9			**133750**	0.20	0.28	6
06/14/2001						0.24	1				0.21	0.24	6
06/14/2001					0.21	0.27	8				0.21	0.24	7
06/15/2001				**139682**						**123597**			
07/20/2001													
11/01/2001		1911	425	**2336**				684	378	**1062**			
12/17/2001		1187	989	**2176**				1901	634	**2535**			

Table 3
Mussel Settlement on Tanks

Sample Date	Plant	Treatment			Control			Treatment			Control		
		Scrape Location	Number of Days	Number/ m²	Scrape Location	Number of Days	Number/ m²	Smallest Measured in mm	Largest Measured in mm	N	Smallest Measured in mm	Largest Measured in mm	N
07/19/2001	Little Gypsy	TBS-1	79	**0**	CB-1	79	**0**						
07/19/2001	Little Gypsy	TBS-2	79	**0**	CBS-1	79	**0**						
07/19/2001	Little Gypsy	TBW-1	79	**0**	CBS-2	79	**0**						
07/19/2001	Little Gypsy	TTS-1	79	**0**	CBW-1	79	**0**						
07/19/2001	Little Gypsy	TB-1	79	**0**	CTS-1	79	**0**						
11/01/2001	Little Gypsy	TT-3	105	**0**	CT-3	105	**25**				2.8	2.8	1
11/30/2001	Russel	TS-1	97	**6505**	CS-1	97	**18036**	0.90	4.7	20	0.9	5	20
11/30/2001	Russel	TS-2	97	**25370**	CS-2	97	**18607**	1.90	5	20	1.5	6.2	20